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EMC ANALYSIS FOR AN/USC-34(XN-1) LINK 11 HF RADIO.(U)
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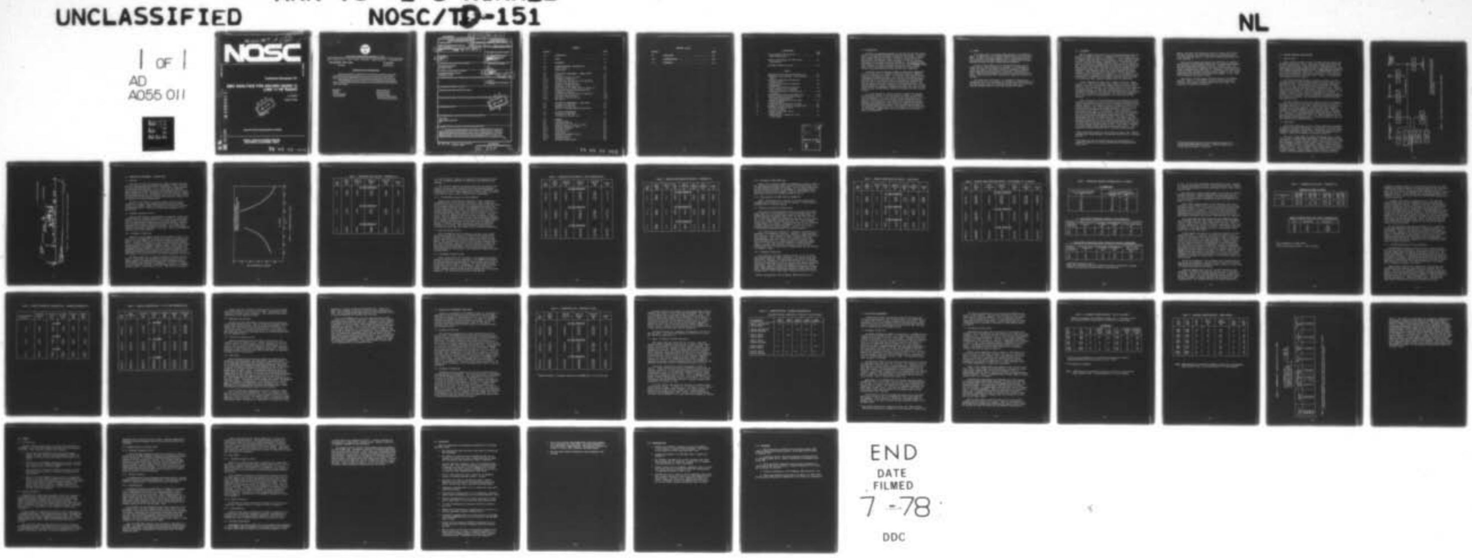

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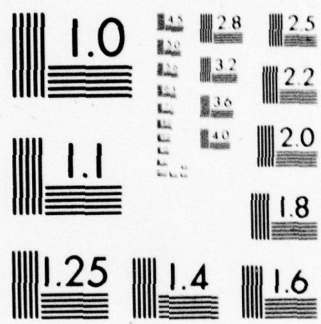

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EMC ANALYSIS FOR AN/USC-34(XN-1) LINK 11 HF RADIO

LJ Kinkel

1 March 1978

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NAVAL OCEAN SYSTEMS CENTER
SAN DIEGO, CALIFORNIA 92152

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ADMINISTRATIVE INFORMATION

Work was conducted by personnel of the Tactical Data Links Office (Code 8245), Naval Ocean Systems Center, performed under project number CC53 (formerly NELC B193), project element PE63519N, and was approved for publication on 24 April 1978.

Acknowledgment and credit is extended to Mr WE Gustafson of Systems Exploration Inc for his fine technical analysis and review of the test data taken on the AN/USC-34 Link 11 radio system.

Released by
RC Kolb
Tactical Command
Control Division

Under authority of
JH Maynard, Head
Command Control-
Electronic Warfare Systems
and Technology Department

(14) NOSC/TR-151

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER
NOSC Technical Document 151 (TD 151)

2. GOVT ACCESSION NO.

3. RECIPIENT'S CATALOG NUMBER
(9) Technical document

4. TITLE (and Subtitle)
(6) EMC ANALYSIS FOR AN/USC-34(XN-1) LINK 11 HF RADIO.

5. TYPE OF REPORT & PERIOD COVERED

6. PERFORMING ORG. REPORT NUMBER

7. AUTHOR(s)
(10) LJ Kinkel

8. CONTRACT OR GRANT NUMBER(s)
~~N00123-76-C-0787~~
~~ASC-243~~

9. PERFORMING ORGANIZATION NAME AND ADDRESS
Naval Ocean Systems Center
San Diego, CA 92152

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
CC53
PE63519N

11. CONTROLLING OFFICE NAME AND ADDRESS
Naval Electronics System Command
Washington, DC 20362

12. REPORT DATE
(11) 1 Ma[redacted]78

13. NUMBER OF PAGES
50 (12) 48p

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)

15. SECURITY CLASS. (of this report)
Unclassified

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)
Approved for public release; distribution is unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)
Link 11 radio
Electromagnetic compatibility
HF

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This document provides information on electromagnetic compatibility (EMC) of candidate shipboard radio systems using the AN/USC-34(XN-1) Link 11 hf radio. Typical antenna and rf distribution systems for both large and small ship classes are included as part of the EMC environment. The AN/USC-34(XN-1) is designed as a lower cost NTDS Link 11 radio, using modified AN/URT-23 transmitter and R-1051/URR receiver. Both measured and analytical results are included as part of the analytical model.

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1.0 INTRODUCTION

The Navy is expanding deployment of the Navy Tactical Data System (NTDS) to increase effectiveness of Task Force operations. As part of this program, NOSC has developed the AN/USC-34 (XN-1) Link 11 System. This system is designed as a lower cost suite for application on smaller ships such as FFG-1, FFG-7 and DDG-2, as well as a possible replacement for existing obsolescent equipments. The AN/USC-34 (XN-1) High Frequency (hf) Radio is a major part of this Link 11 System. The radio consists of standard AN/URT-23 transmitter and R-1051/URR receiver with modifications to make them data mode compatible.

Technical tests are underway at NOSC to demonstrate capabilities of the hf radio prior to scheduled Operational Evaluation (OPEVAL). These tests address three areas: (a) compliance with specifications, including environmental testing; (b) on-the-air link testing; and (c) compatibility of the radio when used in the smaller ship environment. The last area is specifically aimed at demonstrating compatibility when the radio is used with a typical rf distribution system. This testing addresses interface compatibility between radio and rf distribution system, electromagnetic compatibility (EMC) with other hf links using the same rf distribution system and antennas, and other related factors.

It is not feasible to cover all aspects of EMC in the testing; a more general analysis of the EMC problem is needed to supplement the test program. This report contains a detailed analysis to cover areas not included in the testing and provides validation checks. Because of time limitations, the various test programs and the EMC analysis were overlapping. This report has a major portion based on previous measurements and analysis. This was necessary because of the schedule and limitations of the test program. To the extent that it was feasible, summary data from the testing have been included here for verification.

2.0 SCOPE

This report covers the detailed EMC analysis for the AN/USC-34 radio. In particular, it is aimed at smaller ships such as the FFG-1, FFG-7, and DDG-2, with major emphasis placed on these applications. Also covered are replacement applications on larger ships using more broadband antennas and more transmitting multicouplers.

As part of the analysis, the rf distribution system, the antennas, and the other hf radios are included. It is necessary to relate the levels of interference caused by equipments to ambient levels expected from other sources on the ship. Interference to Link 11 from other hf equipments is covered as well as the reverse effect. Typical antenna and rf distribution systems are used in the analysis.

The report does not include: (a) treatment of expected performance of Link 11 in the presence of off-ship noise and interference; (b) interference to and from radiating systems other than hf; or (c) possible coupling effects in the audio distribution system.

3.0 BACKGROUND

EMC measurements and analyses for hf radio systems have been conducted for a number of years. A systematic method of analysis was developed by NOSC and reported in reference 1. This analysis was based on measured characteristics of multicouplers, antenna coupling, transmitters, receivers and ambient shipboard noise. A step-by-step procedure was developed to address each of the factors and its impact on EMC. The base for determining impact was taken as the expected quasi-minimum noise aboard ship. This level was obtained through at-sea measurements during quiet periods of the day on interference-free channels. These measured results were checked against near minimum atmospheric noise as predicted by reference 2. All interference effects caused by equipments are compared to the quasi-minimum levels. Compatibility is assumed if the equipment generated levels are equal to or below this base. Margin or excess levels are identified.

Lack of compatibility arises from a number of factors. Transmitters are a source of broadband noise, harmonics and other spurious signals. Receivers have spurious responses and are subject to overload from local transmitters. This overload results in cross modulation and desensitization. In addition, intermodulation from two or more transmitting frequencies can result from nonlinearities in transmitters, receivers, multicouplers, and antennas. The topside environment is also a major source of intermodulation but is not a part of this analysis.

These effects are very much dependent on the frequency selective circuits in transmitters, receivers, multicouplers and antenna tuners. A major compatibility parameter is that of allowable frequency spacing between channels. The frequency selective circuits are the key to achieving spacing goals. The broadband amplifier circuits of transmitters such as the AN/URT-23 provide very little selectivity; multicouplers must make up the difference. Most shipboard receivers, such as the R-1051/URR, have good selectivity but not sufficient for the very strong interfering signals found aboard ship. Receiving multicouplers provide the added protection. The commonly used AN/URA-38 whip tuner has very little selectivity, and this coupled with broadband transmitters can lead to serious compatibility problems. On the other hand, multicouplers provide very good selectivity, increasing with frequency spacing between channels. This allows a trade-off to be made between channel spacing and interference levels. Link 11 operation is usually conducted with a 15 percent channel spacing.

[1] Naval Electronics Laboratory Center Technical Report 1786, "TRED HF Communications System Analysis", by WM Chase and CW Tirrell, 24 September 1971

[2] CCIR Report No 322, "World Distribution and Characteristics of Atmospheric Radio Noise", Geneva, International Telecommunications Union, 1964

However, operation with spacings as close as 5 percent are the goal for other circuits. For this reason analysis is performed here to first determine EMC impact at 15 percent to examine the potential for closer spacings.

Most circuits aboard ship operate with receivers on a separate antenna spaced a considerable distance from the transmitting antennas. This spacing provides additional protection. However, Link 11 is typically operated with transmitter and receiver on the same antenna using a transmit/receive (T/R) switch. Furthermore, some ships in the future will have the general purpose receivers coupled to the 2-6 MHz broadband antenna through a decoupling device (CARTS - ref 3). This report addresses these separate cases.

Most Link 11 circuits operate with multicouplers on broadband antennas. However, on the smaller ships it will be necessary to operate on whip antennas through a base tuner above 6 MHz. This situation is covered in the analysis.

[3] Naval Electronics Laboratory Center Technical Document 437, "CV-2113(X6-1)/SRC Coupler Isolator: Technical Evaluation" by IC Olson and JL Lievens, 31 July 1975

4.0 ASSUMED SHIPBOARD CONFIGURATIONS

4.1 Smaller Ships

These ships are assumed to have a 2-6 MHz broadband antenna with AN/SRA-56 multicoupler. Two or three whip antennas cover the transmitting requirement above 6 MHz and backup 2-6 MHz requirements. The general purpose receiving complement will be an AN/SRA-49 multicoupler with separate receiving antenna(s) and/or a CARTS decoupler located in the 2-6 MHz transmitting antenna line. The AN/URA-38 base tuner is used with whip antennas. These may be replaced at a later date with the selective base tuner developed by NRL. Figure 1 is a simplified block diagram of the rf system.

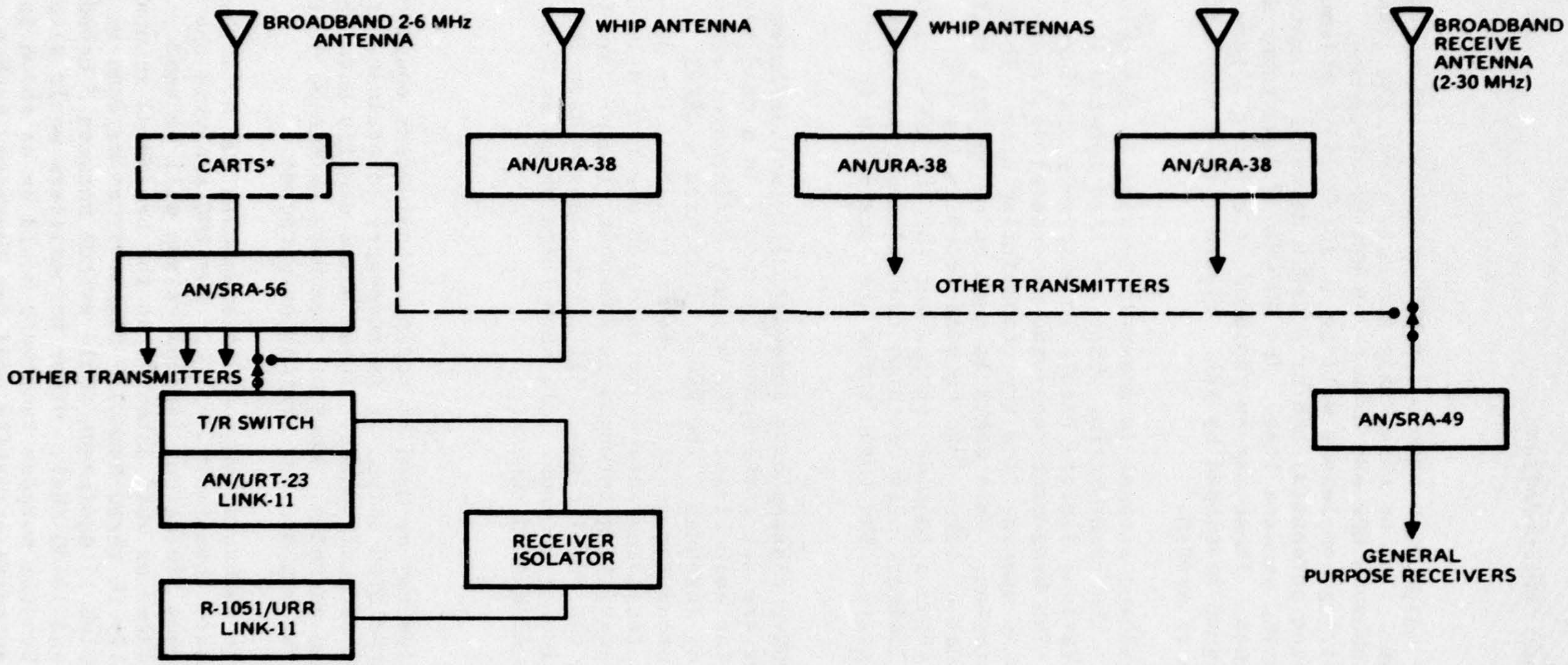
The 2-6 MHz broadband antenna is normally located in the main superstructure area. The transmitting whips are also located in the same general area. Various factors result in whip/whip spacings of only 30 to 50 feet. The broadband receiving antenna(s) is located fore or aft to maximize spacing from the transmitting area. This provides additional isolation. When CARTS is used as an option, this isolation is lost and must be taken into consideration in the EMC analysis. Figure 2 shows a topside arrangement for the FFG-1 class. This sketch of a preliminary plan contains two receiving antennas with one of these on the stern. The three whips are located in the main superstructure area.

The FFG-7 and DDG-2 classes have somewhat different arrangements but these differences are not large enough to result in a need for individual analysis for each class. The primary differences apply to locations of receiving antennas. The FFG-7 class uses a CARTS decoupler and has a broadband receiving antenna forward. The DDG-2 class has a 2-30 MHz receiving antenna forward and one for 10-30 MHz aft. Coupling to transmitting antennas is somewhat greater than for the best location on the FFG-1 class. All three classes have the 2-6 MHz broadband transmitting antenna. All have three whips at about 40 foot spacing and use AN/URA-38 tuners.

4.2 Large Ships

Since these radios may be used to replace obsolescent equipments on presently configured NTDS ships, it is necessary to evaluate effectiveness in that type of environment. These ships usually have three broadband transmitting antennas. Most of them have AN/SRA-34 multicouplers — this will be assumed for evaluation purposes.

There are a large number of antenna arrangements and no attempt will be made to evaluate them individually. For EMC analysis the main difference is in antenna isolation; typical values will be used. Much less dependence is placed on whip antennas as the broadband antennas cover 2-30 MHz (usually in three bands). Figure 1 can be used as a general reference. Link 11 equipment would switch between 3 broadband antennas (2-6, 4-12 and 10-30 MHz). Other transmitters would also be on these antennas. General purpose receivers would be as shown in figure 1, with whip antennas primarily used for emergency backup.



*CARTS decoupling allows reception on the transmitting antenna. Dotted lines designate this as an option to the broadband receive antenna on some ships.

Figure 1. Block Diagram of RF System for Smaller NTDS Ships.

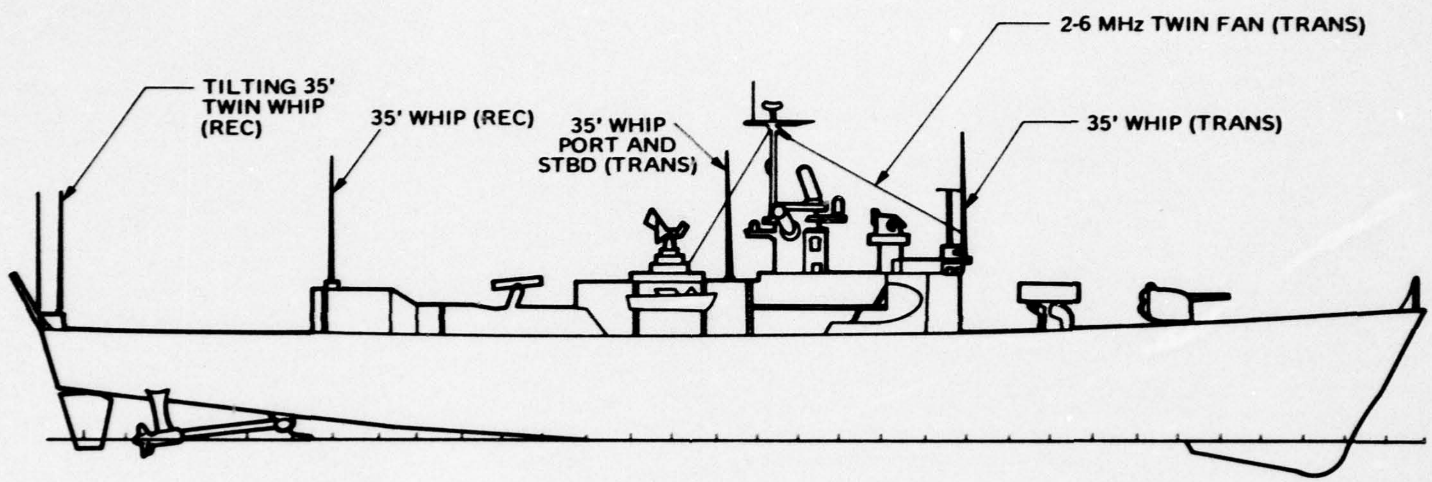


Figure 2. Sketch of HF Antennas for FFG-1 Class (Preliminary).

5.0 COMPUTED EMC PERFORMANCE - SMALLER SHIPS

5.1 Approach

This section covers the computation of EMC performance based primarily on data obtained from previous measurements. Most of the data are from controlled laboratory tests. In some cases it was necessary to extrapolate available data. It is assumed that the AN/USC-34 radio is identical in EMC performance to the AN/URT-23 and the R-1051/URR equipments now in use. Characteristics of multicouplers, transmit/receive antenna isolation, and CARTS are taken from references 1 and 3. Allowable interference levels are taken from reference 1 (table 2) and are referred to as quasi-minimum noise.

The bulk of the results is shown in tabular form with a more limited use of graphs. The primary reference levels are decibels referred to a milliwatt (dBm) and decibels (dB) referred to a receiver or transmitter level. Isolation, coupling and decoupling are also stated in dB.

5.2 Broadband Transmitter Noise

Based on past analyses and measurements, transmitter noise can be a major threat for frequency separations of 5 percent or less between channels. This is particularly so for unfiltered transmitters and/or close coupling between transmitting and receiving antennas. However, for the greater frequency spacing between Link 11 and other circuits (nominally 15 percent) this problem is reduced. The 2-6 MHz multicoupler provides major isolation for this band. However, the AN/URA-38 tuner has very little isolation.

5.2.1 Broadband 2-6 MHz Case

Results for the broadband 2-6 MHz case are shown in table 1. In this case it is assumed that receivers are coupled to the transmitting antenna via either CARTS or the T/R switch in their associated transmitter. The point of reference for the quasi-minimum noise threshold is at the transmitting antenna terminals. Figure 3 shows typical noise characteristics of the AN/URT-23 transmitter with a large decay with increasing frequency separation. Since the isolation provided by the AN/SRA-56 multicoupler also increases with frequency separation, major improvement results from operating at 15 percent. The table shows a large margin at 15 percent but with some system degradation at 5 percent.

The above results are for nominal isolation provided by the AN/SRA-56. In practice, this isolation is reduced by up to 20 dB on occasion because the transmitter and multicoupler impedances are far from 50 ohms at the interference frequencies. This will be referred to as the perturbed isolation. Under the worst case then, the margins listed in table 1 can be reduced by 20 dB. This leads to no problem

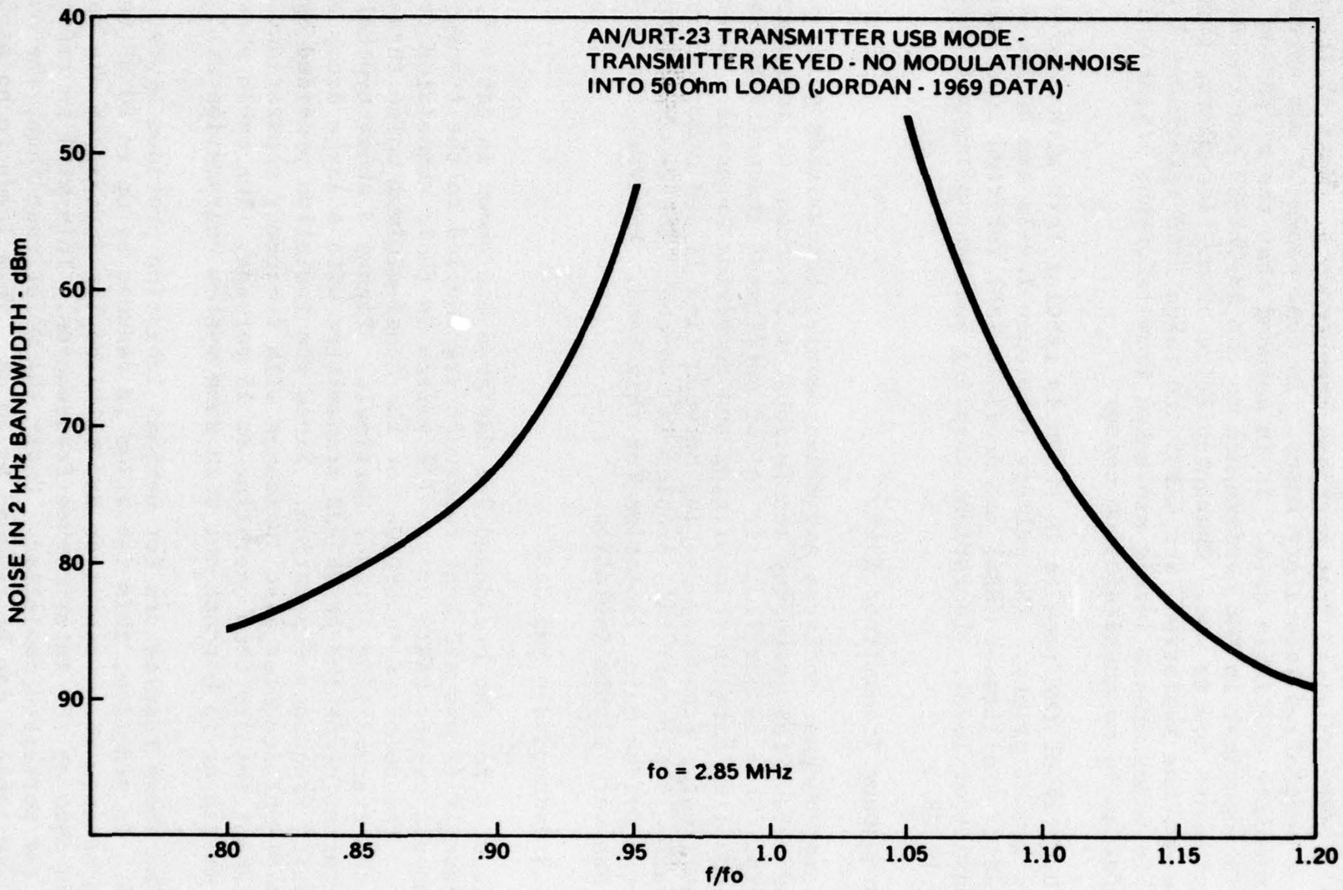


Figure 3. Broadband Transmitter Noise.

TABLE 1. TRANSMITTER NOISE ANALYSIS - BROADBAND T/R.

Freq MHz	Xmtr Output dBm	SRA-56 Isolation dB	Noise at Antenna dB	Quasi-Min Noise dBm	Margin dB
			15% FREQ SEPARATION		
2	-80	59	-139	-87	52
4	-80	59	-139	-95	44
6	-80	59	-139	-100	39
			10% FREQ SEPARATION		
2	-70	52	-122	-87	35
4	-70	52	-122	-95	27
6	-70	52	-122	-100	22
			5% FREQ SEPARATION		
2	-48	40	-88	-87	1
4	-48	40	-88	-95	-7
6	-48	40	-88	-100	-12

at 15 and 10 percent. However, at spacings of less than about 9 percent, an increasing probability of significant interference can be expected.

The case for a separate receiving antenna was not treated in the table; it is improved by a factor equal to the decoupling between transmitting and receiving antennas. From reference 1 (table 21) this decoupling is 10 dB at 2 MHz increasing to 16 dB at 6 MHz. This would allow operation down to about 7 percent with no degradation.

5.2.2 6-30 MHz Whip Antenna Case With AN/URA-38

For the case of 6-30 MHz and transmitting on whip antennas via the AN/URA-38 the results are quite different. Table 2 shows the results for the case of receiving on an adjacent whip via the T/R switch. For an assumed separation of 35 feet the decoupling increases from 12 dB at 6 MHz to 26 dB at 30 MHz. The AN/URA-38 tuner provides very low and unpredictable isolation; it was assumed to be zero at the frequency separations listed. Results show a deficiency of 3 to 8 dB at 15 percent and large deficiencies at 10 and 5 percent. Unfortunately, increased separation does not provide a guarantee of reduced levels. Since the AN/URA-38 will provide a small additional isolation on the average, operation at 15 percent should not be degraded appreciably. Operation at separations of less than 15 percent should be avoided. A separate receiving antenna will provide an additional isolation of 5 to 10 dB. This could eliminate the deficiency at 15 percent but would have only a small effect at smaller separations.

5.3 Receiver Overload Effects

The R-1051/URR receiver is designed to operate in the strong-signal ship environment. However, it requires some additional protection to attenuate the strong local signals to acceptable levels. This is usually provided by receiving multicouplers such as the AN/SRA-49. The overload effects result in loss of gain, desensitization and cross modulation. These effects become important at nearly the same level of interfering signal. The most data were available on cross modulation and these were used to establish allowable interference threshold at the receiver. Three cases were treated and these are shown below.

5.3.1 Broadband 2-6 MHz T/R Case

Table 3 shows results for receiving on the transmitting antenna through the T/R switch on the transmitter. The AN/SRA-56 multicoupler provides isolation but an additional 20 dB pad is also used as part of the receiver isolator shown in figure 1. The isolator also includes filters identical to those of the AN/SRA-49. The 2-6 MHz filter can be used in place of the 20 dB pad to further reduce the threat if needed. Results show that the 20 dB pad is adequate even for 5 percent separation. The filter would allow even closer spacing.

TABLE 2. TRANSMITTER NOISE ANALYSIS - WHIP ANTENNAS/URA-38.

Freq MHz	Xmtr Output dBm	Antenna Isolation dB	Noise at Antenna dB	Quasi-Min Noise dBm	Margin dB
			15% FREQ SEPARATION		
6	-80	12	-92	-100	-8
10	-84	17	-101	-106	-5
15	-84	20	-104	-111	-7
20	-88	22	-110	-114	-4
30	-90	26	-116	-119	-3
			10% FREQ SEPARATION		
6	-70	12	-82	-100	-18
10	-76	17	-93	-106	-13
15	-80	20	-100	-111	-11
20	-83	22	-105	-114	-9
30	-83	26	-109	-119	-10
			5% FREQ SEPARATION		
6	-48	12	-60	-100	-40
10	-56	17	-73	-106	-33
15	-58	20	-78	-111	-33
20	-58	22	-80	-114	-34
30	-58	26	-84	-119	-35

TABLE 3. RECEIVER CROSS MODULATION ANALYSIS - BROADBAND T/R.

Freq MHz	Xmtr Output dBm	SRA-56 Loss dB	Pad Loss dB	SRA-56 Off-Freq dB	Rcvr Threat dBm	Rcvr Threshold dBm	Margin dB
			15% FREQ SEPARATION				
2	+60	2	20	59	-21	>+28	>49
4	+60	2	20	59	-21	>+28	>49
6	+60	2	20	59	-21	>+28	>49
			10% FREQ SEPARATION				
2	+60	2	20	52	-14	+28	49
4	+60	2	20	52	-14	+28	49
6	+60	2	20	52	-14	+28	49
			5% FREQ SEPARATION				
2	+60	2	20	40	-2	+8	10
4	+60	2	20	40	-2	+8	10
6	+60	2	20	40	-2	+8	10

5.3.2 Broadband 2-6 MHz CARTS Case

Results for receiving on CARTS with AN/SRA-49 are shown in table 4. This represents the general purpose receiver interference from Link 11 or other transmitters using this antenna. The very large margins indicate the protection inherent in the AN/SRA-49. Separations of much less than 5 percent would be possible, except that broadband transmitter noise precludes this anyway as shown in table 1.

5.3.3 Whip Antennas; 6-30 MHz Case With AN/URA-38

Table 5 shows results for reception on one whip antenna while transmitting on a second one at a 35 foot spacing. A large margin is available even at 5 percent spacing.

5.4 Transmitter Generated Intermodulation

This source of intermodulation results from energy reaching the output stage of a victim transmitter via the radiating system. This energy mixes with the desired signal energy in the output stage to generate undesired frequencies such as $F1 \pm F2$, $2F1 \pm F2$, $F1 \pm 2F2$, etc. A very large number of possibilities exist when even more transmitters are considered and higher order (ie, $4F1 \pm 3F2$) intermodulation products are included. Intermodulation also occurs at moderate to high levels in the topside environment. It can occur in the receiving subsystem if poorly designed. Finally, it can occur in rf distribution subsystem hardware such as multicouplers.

Very limited data are available on transmitter intermodulation as measured at the transmitter terminals. Reference 4 reports measurements made on a linear transmitter under controlled laboratory measurement procedures. The first part of table 6 shows the 3rd order intermodulation levels as a function of interfering signal level. Since intermodulation is so highly dependent on interfering signal level, it is clear that isolation provided by transmitting multicouplers, antenna tuners and space isolation is very important. Unfortunately, data for higher order intermodulation were not obtained in reference 4 tests.

5.4.1 Broadband 2-6 MHz Case

The second part of table 6 contains results for use of an AN/SRA-56 multicoupler and linear transmitter. The second column lists multicoupler isolation. The third column shows expected intermodulation at the transmitter as derived from the first part of the table. The fourth column shows the level at antenna after passing through the multicoupler. The last column shows measured results of a system mockup using AN/URT-23 transmitters, AN/SRA-56 multicoupler and dummy load. These unpublished results were obtained at NOSC (Naval Ocean Systems Center), formerly NELC (Naval Electronics Laboratory Center)

[4] Private correspondence from FE Edmonds, DECO Electronics, Inc

TABLE 4. RECEIVER CROSS MODULATION ANALYSIS - CARTS/SRA-49.

Freq MHz	Xmtr Output dBm	SRA-56 Loss dB	Carts Loss dB	SRA-49 Isolation dB	Rcvr Threat dBm	Rcvr Threshold dBm	Margin dB
			15% FREQ SEPARATION				
2	+60	2	26	>104	<-72	>+28	>100
4	+60	2	20	>104	<-72	>+28	>100
6	+60	2	17	>104	<-72	>+28	>100
			10% FREQ SEPARATION				
2	+60	2	26	104	<-72	+28	100
4	+60	2	20	97	-59	+28	87
6	+60	2	17	93	-52	+28	80
			5% FREQ SEPARATION				
2	+60	2	26	80	-48	+8	56
4	+60	2	20	73	-35	+8	43
6	+60	2	17	69	-28	+8	36

TABLE 5. RECEIVER CROSS MODULATION ANALYSIS - WHIP ANTENNAS (35 ft SPACING).

Freq MHz	Xmtr Output dBm	Whip Decoupling dB	SRA-49 Off-Freq dB	Rcvr Threat dBm	Rcvr Threshold dBm	Margin dB
			15% FREQ SEPARATION			
6	+60	12	>100	<-52	>+28	>80
10	+60	17	>100	<-57	>+28	>85
15	+60	20	>100	<-60	>+28	>88
20	+60	22	>100	<-62	>+28	>90
30	+60	26	>100	<-62	>+28	>90
			10% FREQ SEPARATION			
6	+60	12	93	-45	+28	73
10	+60	17	89	-46	+28	74
15	+60	20	85	-45	+28	73
20	+60	22	82	-44	+28	72
30	+60	26	78	-44	+28	72
			5% FREQ SEPARATION			
6	+60	12	69	-21	+8	29
10	+60	17	65	-22	+8	30
15	+60	20	61	-21	+8	29
20	+60	22	58	-20	+8	28
30	+60	26	54	-20	+8	28

TABLE 6. TRANSMITTER GENERATED INTERMODULATION (3rd ORDER).

A. AT TRANSMITTER

Level of Interfering Signal Below Desired Signal dB	3rd Order Intermodulation at Desired Signal Transmitter*	
	dB down	dBm
-7	32	+28
-10	43	+17
-15	53	+7
-20	57	+3
-25	63	-3
-30	81	-21
-40	100	-40

B. WITH AN/SRA-56 PROTECTION (NOMINAL 50 OHM SOURCE/LOAD)

Frequency Separation in Percent	Nominal Isolation in SRA-56 dB	Calculated Intermodulation		Measured Intermod** at Load (1970 data) dBm
		at Trans dBm	at Load dBm	
2.5	28	-10	-38	-38
5.0	40	-40	-80	-56
10.0	52	<-40	<-92	-67

C. WITH AN/SRA-56 PROTECTION (ACTUAL SYSTEM WITH AN/URT-23 TRANSMITTER)

Frequency Separation in Percent	Perturbed Isolation in SRA-56*** dB	Calculated Intermodulation		Worst Case Intermod Meas at Load (1976 data)*** dBm
		at Trans dBm	at Load dBm	
2.5	14	+9	-19	-22
5.0	20	+3	-37	-35
10.0	32	-26	-78	-59

*From DECO measurements (ref 4)
**1976 data obtained at NELC with AN/SRA-56 and URT-23 transmitters (average)
***Worst case perturbed isolation based on available data

in 1976. At 2.5 percent separation the correlation is good. However, at 5 percent and greater it is poor. This is believed to be a result of intermodulation generated in the multicoupler itself; other evidence points to this.

The third part of table 6 shows results for the case of perturbed AN/SRA-56 isolation. Computed and measured results agree well at 2.5 and 5 percent but not at 10 percent. This is again beleived to be a result of multicoupler intermodulation which is probably in the range of -60 dBm.

Table 7 shows measured results of 3rd and higher order intermodulation taken at NOSC in 1976. The 3rd order values are the same as listed in table 6. Also included are the ranges of topside intermodulation levels for reference. It is evident that multicoupler contribution is the main source at least at 10 percent separation. Computations were not made for the 15 percent case because of the multicoupler uncertainty and the lack of measured data for comparison.

It is clear that 3rd order levels from the transmitting system are considerably above the lower range of topside levels (-59 dBm max versus -77 dBm). However, table 6 shows worst case level expected from the transmitter at -78 dBm for 10 percent separation. This would be another 15 dB or more down at 15 percent. This indicates that the transmitter is more than adequate and that any improvements needed must be made in the multicoupler.

No measurements were made at the transmitter terminals for data presented in table 7. Since data reported in reference 4 did not include 5th and higher orders, it is necessary to rely on other means to predict their levels. An attempt was made to deduce transmitter levels from the multicoupler output measurements. However, results are very uncertain because of intermodulation in the multicoupler. For this reason an older set of measurements was used in which data were obtained at the transmitter terminals. Because of measurement procedures, absolute values are not accurate. However, relative levels between 3rd and 5th orders are accurate. A different transmitter, the AN/FRT-39, was used instead of the AN/URT-23. This is also a linear transmitter and should be representative of this class of operation. Comparison of average data points shows a 43 dB reduction between 3rd and 5th orders.

No data are available on 7th and higher order intermodulation as measured at the transmitter. Results of table 7 were used to obtain some indication of reduction between 5th and 7th orders. A lower level of 20 dB was obtained with this method.

Using the computed worst case for 3rd order from table 6 and allowing for the above 43 dB reduction, the 5th order is expected to be -92 dBm. This is for 5 percent separation and it is referred to multicoupler output. This is 6 dB below the measured value in table 7 and only 5 dB above the lowest expected level of topside 5th order intermodulation. For average values and for greater spacings the

TABLE 7. INTERMODULATION ANALYSIS - BROADBAND T/R.

MEASURED AT AN/SRA-56 OUTPUT*

Freq Separation in %	3rd Order		5th Order		7th Order		9th Order	
	Avg dBm	Max dBm	Avg dBm	Max dBm	Avg dBm	Max dBm	Avg dBm	Max dBm
2.5	-38	-22	-74	-54	-105	-81	-111	-98
5.0	-56	-35	-94	-86	-110	-102	-120	-116
10.0	-67	-59	-100	-90	-112	-106	-127	-123

RANGE OF EXPECTED VALUES FROM TOPSIDE INTERMODULATION

Order	Maximum-dBm	Minimum-dBm
3rd	-47	-77
5th	-67	-97**
7th	-82	-112**
9th	-97	-127**

*1976 measurements at NOSC (NELC).

**Very limited data available - lots of scatter.

transmitter component would be far less and well below even the quasi-minimum noise design threshold. The same procedure for 7th order leads to an expected level of -120 dBm at the multicoupler output. This worst case is far below quasi-minimum noise (-100 dBm at 6 MHz). Table 8 summarizes results. It is concluded that transmitter generated intermodulation is not a significant threat for 5th and higher orders even at 5 percent separation.

In summary, multicoupler intermodulation is a more important limitation than that from the transmitter except at frequency separations approaching 5 percent. Except for 3rd order, the differences between 5 percent and 10 percent are small and far less than expected from the transmitter source. Importance of the multicoupler as a source of intermodulation can be assessed by comparing measured results to expected topside levels shown in table 7. For 3rd order the multicoupler levels are well above minimum topside levels even at 10 percent. However, for 5th and higher order, the averages are near minimum topside levels even for 5 percent separation. The worst cases are only about 10 dB higher than the minimum topside levels. Frequencies with 3rd order intermodulation should be avoided in any case, as the expected topside levels are too high.

For 7th and higher orders the multicoupler is not a limitation as the quasi-minimum noise design goal is -100 dBm or greater in the 2-6 MHz band. The worst case, 5th order, is significantly higher than -100 dBm. However, the combined probabilities of minimum topside levels, of minimum ambient noise levels, of receiving on a 5th order frequency, and of worst case multicoupler levels are very small. These considerations indicate that multicoupler intermodulation is not a serious threat and that the transmitter is not a significant threat even at 5 percent separation.

5.4.2 6-30 MHz Whip Antenna Case With AN/URA-38

Intermodulation should be a much more serious threat with whip antennas when using the AN/URA-38. The very poor isolation offered by the tuner leaves mainly the antenna decoupling for protection. Expected intermodulation was computed using nominal values of isolation between whip antennas. It was assumed that three whips are spaced 35 feet apart on a triangle. Nominal decoupling shown in table 2 was used between two transmitting whips and between each of them and the third whip being used to receive. For these computations it was assumed that no isolation was added by the tuner.

Table 9 shows results of the computations. Expected 3rd order intermodulation was obtained using results from the first part of table 6. Levels at the transmitters (column 3 of table 9) were transferred to the receiving whip using the nominal whip/whip decoupling. Results for 5th order were obtained by assuming a 43 dB reduction from 3rd order values as discussed in subsection 5.4.1. Another 20 dB reduction was used for obtaining 7th order levels. The table also shows topside intermodulation and quasi-minimum noise levels.

TABLE 8. COMPUTED TRANSMITTER INTERMODULATION - BROADBAND ANTENNA/SRA-56.

Freq Separation In Percent	Perturbed Isolation dB	Intermod at Tx dBm	Intermod at Load dBm	Topside Max dBm	Topside Max dBm
			3rd ORDER		
5	20	+3	-37	-47	-77
10	32	-26	-78	-47	-77
15	39	-38	-97	-47	-77
			5th ORDER		
5	20	-40	-92	-67	-97
10	32	-69	-129	-67	-97
15	39	-81	-141	-67	-97
			7th ORDER		
5	20	-60	-120	-82	-112
10	32	-89	-149	-82	-112
15	39	-101	-161	-82	-112

TABLE 9. COMPUTED INTERMODULATION - 35 foot WHIP ANTENNAS/URA-38.

Freq MHz	Whip Decoupling dB	Intermod at Tx dBm	Intermod at Rx dBm	Topside Max dBm	Topside Min dBm	Quasi-Min Noise dBm
			A. 3rd ORDER			
6	12	+12	0	-47	-77	-100
10	17	+6	-11	-47	-77	-106
15	20	+3	-17	-47	-77	-111
20	22	+1	-21	-47	-77	-114
30	26	-5	-31	-47	-77	-119
			B. 5th ORDER			
6	12	-31	-43	-67	-97	-100
10	17	-37	-54	-67	-97	-106
15	20	-40	-60	-67	-97	-111
20	22	-42	-64	-67	-97	-114
30	26	-48	-74	-67	-97	-119
			C. 7th ORDER			
6	12	-51	-63	-82	-112	-100
10	17	-57	-74	-82	-112	-106
15	20	-60	-80	-82	-112	-111
20	22	-62	-84	-82	-112	-114
30	26	-68	-94	-82	-112	-119

Results show that transmitter intermodulation can be much higher than topside levels even for 5th and 7th order. Even maximum topside levels are exceeded at some frequencies. This indicates that serious interference can be expected at times.

5.5 SACS Whip Tuner Analysis

The Navy has under development a new whip tuner with greatly improved filter characteristics. This is the Selective Antenna Coupling System (SACS) being developed by the Naval Research Laboratory. It consists of a base tuner at the whip antenna and a filter located in the transmitter area. Preliminary characteristics are available and these have been evaluated to determine impact on the EMC problems found with the AN/URA-38 tuner.

5.5.1 Selectivity Characteristics

Laboratory measurements have been made to determine the off-frequency isolation characteristics. Nominal values are in the range of 35 to 55 dB at 5 percent separation in the 2-30 MHz band. At 10 percent, this increases by another 12-18 dB. These nominal values are generally as good as those for the AN/SRA-56 multicoupler. Perturbed isolation is about 20 dB worse than nominal values which is essentially the same as for the multicoupler.

5.5.2 EMC Impact

Since the SACS selective tuner has roughly the isolation characteristics of the multicoupler, the same general conclusions apply. In the 2-6 MHz band transmitter noise is about as shown in table 1 except for an additional 12 dB margin from whip/whip decoupling. Operation at 7½ percent should be acceptable when allowance is made for perturbed isolation. No problem from receiver overload should occur as the margins shown in table 3 apply. Intermodulation should be lower than levels shown in table 6 because of the extra 12 dB decoupling between transmitters and the additional 12 dB decoupling to the receiving antenna. Levels should be down from computed levels in the table by 25 to 30 dB. This assumes that the SACS selective tuner does not generate intermodulation itself. This must be proved through later tests. The AN/URA-38 tuner does generate intermodulation. Very limited data on 3rd order only are available, so computations were not attempted here. This is discussed in a following section on recent verification tests. Transmitter generated intermodulation should not be a problem.

In the 6-30 MHz band comparisons are made with results of tables 2, 5 and 9 (results with the AN/URA-38). Levels of transmitter noise shown in table 2 should be down by 35 dB at 5 percent, 47 dB at 10 percent, and 54 dB at 15 percent (all nominal values). This leads to large margins at 10 and 15 percent. At 5 percent there is a slight deficiency with nominal values, increasing to a deficiency of 25 dB for worst case.

Operation at 7 percent should be interference free. Results in table 5 were examined to determine possible receiver overload problems. The very large margins shown there would be increased by 35 dB if both the AN/SRA-49 and the SACS tuner were used.

Even if the AN/SRA-49 were not used, operation down to about 5 percent would be possible. Results of table 9 were used to assess improvements when using the SACS tuner. A minimum of 65 dB reduction is expected for 5th and higher order intermodulation with frequency separation of 5 percent or more. This leads to values that are lower than quasi-minimum noise. For 3rd order the expected reduction is 52 dB or more. This leads to a worst case level of -52 dBm at 6 MHz and -83 dBm at 30 MHz at 5 percent separation. Since operation on 3rd order intermodulation frequencies must be avoided anyway, the fact that levels are well above quasi-minimum noise is not a consideration. Topside intermodulation imposes this constraint. Operation with the SACS tuner should be possible down to 5 percent separation in regard to transmitter intermodulation. Tests must be made to assure that tuner intermodulation is at acceptable levels.

6.0 EXPECTED EMC PERFORMANCE-LARGE SHIPS

Analysis of performance of the AN/USC-34 radio for replacement on large ships is not as detailed as that presented for smaller ships. Three main differences in characteristics are: (a) use of broadband antennas and transmitting multicouplers for 6-30 MHz; (b) somewhat increased decoupling to the main receiving antenna(s); and (c) the frequency separations between channels. Most of this section addresses these differences and their impact on conclusions reached in preceding sections.

6.1 Broadband 2-6 MHz Case

This antenna has essentially the same characteristics as for smaller ships. The AN/SRA-34 multicoupler also has essentially the same characteristics of isolation and insertion loss as the AN/SRA-56. Because of these similarities the results shown in tables 1, 3, 4, 6, 7 and 8 apply. Broadband transmitter noise would limit operation to about 9 percent frequency separation when receiving via the T/R switch or 7 percent if a separate receiving antenna were used. Closer spacings could be used if a small probability of interference were allowable. No receiver overload problem is expected even at 5 percent. Transmitter generated intermodulation is not expected to be a threat at 5th and higher order frequencies at spacings down to 5 percent. Although 3rd order levels are expected to be well above minimum topside levels, these frequencies should be avoided in any event as the topside levels pose a major threat. Intermodulation generated in the AN/SRA-34 is believed to be about the same or somewhat less than that shown in table 7 for the AN/SRA-56. Only very limited data are available. No serious threat is expected for 5th and higher orders even at 5 percent separation.

6.2 Broadband 6-30 MHz Case

Transmitter noise is expected to be much less a problem than for the whip antennas and AN/URA-38. Table 10 shows results of computations for 6-30 MHz using multicouplers. The table contains data for nominal isolation which should be valid for the AN/SRA-34 as it contains circuitry to minimize perturbations. Results indicate that operation at 10 percent provides some margin in the lower half of the range and operation to about 8 percent should be possible. If AN/SRA-57/58 multicouplers are used, a 20 dB reduction in isolation can occur a small part of the time. In that event, separations of 10 percent at 6 MHz up to 15 percent at 30 MHz will be required to preclude transmitter noise interference. Use of a separate receiving antenna should provide an additional 16 to 36 dB of isolation from 6 to 30 MHz. This would allow operation down to 5 percent with the AN/SRA-34 and down to about 7 percent with the AN/SRA-57/58 multicoupler.

TABLE 10. TRANSMITTER NOISE - BROADBAND 6-30 MHz.

Freq MHz	Xmtr Output dBm	SRA-34* Isolation dB	Noise at Antenna dBm	Quasi-min Noise dBm	Margin dB
			15% FREQ SEPARATION		
6	-80	59	-139	-100	39
10	-80	59	-139	-106	33
15	-80	59	-139	-111	28
20	-80	59	-139	-114	25
30	-80	59	-139	-119	20
			10% FREQ SEPARATION		
6	-70	52	-122	-100	22
10	-70	52	-122	-106	16
15	-70	52	-122	-111	11
20	-70	52	-122	-114	8
30	-70	52	-122	-119	3
			5% FREQ SEPARATION		
6	-48	40	-88	-100	-12
10	-48	40	-88	-106	-18
15	-48	40	-88	-111	-23
20	-48	40	-88	-114	-26
30	-48	40	-88	-119	-31

*Nominal isolation - perturbed isolation with AN/SRA-56/57 can be 20 dB less.

Receiver overload is not expected to be a problem when using the AN/SRA-49 type filter in series with the multicoupler. This is part of the proposed Link 11 setup above 6 MHz as shown in figure 1. Results in table 3 apply except that an additional 34 dB or more isolation is obtained by using the filter in place of the 20 dB pad. If the filter is not used, a 10 dB deficiency would occur at 5 percent because the 20 dB pad cannot be used at these higher frequencies. Operations down to about 6 percent should be possible without the filter. Use of a separate receiving antenna with the AN/SRA-49 would provide operation at well below 5 percent separation.

Conclusions reached for transmitter intermodulation for the 2-6 MHz case apply. The results are discussed in subsection 6.1 and in more detail in subsection 5.4.1.

6.3 Impact of Frequency Spacing Constraints

Some larger ships may require 8-10 hf circuits. This poses greater frequency management problems than for smaller ships, and it becomes more important to achieve smaller frequency spacings. The greatest threat is from transmitter noise insofar as small frequency spacings are concerned. Topside intermodulation poses the greatest threat otherwise, unless the minimum expected levels are achieved. Since transmitter intermodulation is not expected to cause significant problems and since receiver overload is not a problem, transmitter noise is the main concern regarding equipment adequacy. Minimum spacings of 9 percent for 2-6 MHz and 15 percent for 6-30 MHz are required to preclude occasional degradation when using AN/URT-23s, AN/SRA-56/57/58 and when using the transmitting antenna to receive.

Alternative configurations provide improvement as shown in table 11. These separations are based on transmitter noise being the dominant constraint. A 10 percent separation is achievable with all configurations except for the AN/URT-23, AN/SRA-56/57/58 and common antenna which exceeds this above 10 MHz. Use of a separate antenna brings those equipments within the limit. Since the AN/SRA-34 is on a number of ships, configurations using it were included. It provides considerably improved performance and with a separate antenna allows separations of 5 percent or less.

It is not clear at what point the constraint of a greater separation becomes serious. It probably is in the range of 5 to 10 percent with 10 percent probably being acceptable. Also the constraint is probably of more concern in the 2-6 MHz band. Somewhat greater values may be allowable above 6 MHz. Based on these considerations, the noise from the AN/URT-23 is of some concern but probably not serious.

TABLE 11. TRANSMITTER NOISE - ALTERNATE CONFIGURATIONS.

Allowable Frequency Separation in Percent at the Following:

Configuration	2 MHz	6 MHz	10 MHz	20 MHz	30 MHz
URT-23, SRA-56/57/58 Common antenna	7.5	9	10	13	15
URT-23, SRA-56/57/58 Separate antennas	6	7	7.5	6.5	7
URT-23, SRA-34 Common antenna	5	6.5	7	9	10
URT-23, SRA-34 Separate antennas	<5	5	<5	<5	5
SRC-23, SRA-34 Common antenna	<<5	<5	5	6	6.5
SRC-23, SRA-34 Separate antenna	<<5	<<5	<<5	<<5	<<5

7.0 VALIDATION MEASUREMENTS

A measurement program was underway during the same period that this report was developed. Some of these results are included here as a further check on the foregoing computations and conclusions. These measurements (ref 5) were primarily aimed at demonstrating feasibility of the rf distribution system design for smaller ships when using AN/URT-23 transmitters and R-1051/URR receivers.

7.1 Broadband 2-6 MHz Case

The mockup included two AN/URT-23 transmitters, an AN/SRA-56 multicoupler and an R-1051/URR receiver. The transmitters were modified for submarine use and were set up for 400 Hz power. A dummy load was used in place of an antenna. The first measurements were made on transmitter noise at 15 percent frequency spacing at 22 points in the band. Results for one transmitter show an average value of -109 dBm and a maximum of -95 dBm. Corresponding values for the other transmitter were -126 dBm and a maximum of -98 dBm. The measurements were made at the multicoupler output and can be compared to results in table 1. The average values are much above the -139 dBm expected at 15 percent. However, one transmitter was higher than the other by 17 dB. At 5 percent the average values were -81 and -89 dBm on the two transmitters while the maximum values were -58 and -74 dBm. The predicted average value in table 1 is -88 dBm.

The measured averages are much above predicted levels at 15 percent but reasonably near these levels at 5 percent. One transmitter was considerably worse than the other at both separations. Interference estimates made in preceding sections assumes a perturbed isolation 20 dB worse than average. The measurements are in good agreement with the estimates. The problem of higher noise in the measurements is of serious concern. However, later measurements on whip antennas used other AN/URT-23 transmitters with 60 Hz power; these showed results near predicted values. This is discussed in section 7.2.

Measurements of intermodulation at 15 percent separation showed average 3rd order to be -75 dBm. For 5th order the corresponding level was -95 dBm. At 5 percent the average 3rd order was -60 dBm and the average 5th was -97 dBm. The results are in reasonable agreement with those shown in table 6 and 7. The same conclusion is drawn that the multicoupler rather than transmitter is the primary source at separations greater than 5 percent.

No indication of receiver overload was found in any of the tests when using a 20 dB pad out of the AN/SRA-56 or when using CARTS and the AN/SRA-49. This confirms the expectation that ample margin is available down to at least 5 percent and that transmitter noise is the dominant factor.

[5] Naval Ocean Systems Center Technical Document 161, "Small Ship RF Distribution Evaluation For AN/USC-34," by RL Dickson (in preparation)

The limited intermodulation tests indicated that CARTS was the source in some instances. The 5th order was found to be up to 10 dB higher than that from the AN/SRA-56. The 3rd order was also higher for 15 percent separation but this is not as important as those frequencies should be avoided anyway. Further measurements on CARTS intermodulation are indicated to determine if these limited results are typical.

7.2 6-30 MHz Whip Antenna Case

Measurements were made using a spacing of 35 feet between whip antennas. Only one AN/URA-38 tuner was available and it was put in the transmitter line. The receiver was put on the other whip with AN/SRA-49 in series for noise measurements. Results for 15 percent frequency separation are shown in table 12. The last column shows noise levels referred back to the transmitter terminals. Comparison of these results to those of table 2 show reasonable agreement considering the uncertainty of the AN/URA-38 isolation which was assumed to be zero in table 2. Measurements were also made directly at the transmitter terminals and these are shown in table 13.

Results can be compared to those of figure 3. Most values are within a few dB of those shown in figure 3 for f/fo of 0.87 and 1.15. Since the figure is only a typical curve, some departure can be expected. In any event, results are near expected levels which is quite different from results using the 400 Hz power with modified transmitters as discussed in subsection 7.1. This indicates a need for further measurements to resolve the discrepancy.

Table 12 (6th column) shows noise measured at the receiver terminals. Noise at the antenna can be determined by correcting for multicoupler loss. Making this correction and comparing results to quasi-minimum noise in table 2, shows levels close to design threshold in most instances. This is in agreement with the small negative margins shown in table 2 for 15 percent.

Intermodulation measurements were somewhat inconclusive because of the high residual levels when radiating. The test setup used two whip antennas with 35 foot spacing, with AN/URA-38 for one whip. The second was untuned. An untuned probe receiving antenna was placed near the two whips. All measurements were made with a pair of frequencies at 15 percent separation. Table 14 shows results of the measurements. The 7th column shows results most pertinent to possible constraints. Comparison of these to topside levels in table 9 shows that even maximum, expected, topside levels are exceeded by 11 dB or more for all three orders.

The 3rd order values in the 7th column are at or below those computed values in table 9 (4th column). Refer to data points at 6 and 10 MHz as the transmitting frequencies were about 5.9 and 6.8 MHz. For 5th and 7th order the values are near expected values shown in

TABLE 12. BROADBAND TRANSMITTER NOISE - TWO 35 foot WHIPS.

AN/URT-23 Transmitter with AN/URA-38 antenna tuner - receiving on other whip through AN/SRA-49 multicoupler (no URA-38 in receiving whip).

RX TERMINALS

TX Freq kHz	RX Freq kHz	RX NF dB	AMBIENT Noise dB/RX	TX Noise dB/RX	TX Noise dBm	COUPLING TX/RX dB*	APPARENT TX Noise dBm**
6835	5810	12	18	21	-109	-27	-82
6835	7860	12	11	19	-108	-28	-80
9305	8333	13	10	13	-116	-29	-87
9305	11274	11	6	7	-128	-34	-94
16100	13685	12	14	14	<-120	-37	<-83
16100	18515	14	12	18	-108	-34	-74

*Coupling includes AN/SRA-49 loss and URA-38 and whip/whip isolation. Coupling between whips alone was about 12 dB at 6 MHz.

**At transmitter terminals.

NOTE: dB/RX denotes the attenuation required to result in a 3 dB increase above receiver noise. Al noise measured in a 3 kHz bandwidth.

TABLE 13. BROADBAND TRANSMITTER NOISE - DUMMY ANTENNA.

TX Freq kHz	RX Freq kHz	RX NF dB	SRA-49 Loss dB	Dummy Coupling dB	TX Noise dB/RX	TX Noise dBm
2300	2000	12	14	-30	6	-77
2300	2600	9	13	-30	11	-76
5865	4985	12	10	-30	2	-85
5865	6745	12	10	-30	2	-85
6835	5810	12	10	-30	6	-81
6835	7860	12	9	-30	2	-86
9803	8333	13	9	-30	9	-78
9803	11274	11	8	-30	-6	-96
16100	13685	12	8	-30	-1	-90
16100	18515	14	6	-30	13	-76

NOTE: dB/RX denotes the attenuation required to result in a 3 dB increase above receiver noise. All noise measured in a 3 kHz bandwidth.

TABLE 14. INTERMODULATION - AN/URT-23s ON TWO 35 foot WHIPS.

T1 on AN/URA-38 tuner -- f = 5865 kHz
T2 on whip without tuner -- f = 6835 kHz
Receiver on probe antenna (h = 10 feet) with
AN/SRA-49 multicoupler
35 foot whip spacing - 35 feet

RX Freq kHz	Intermod Order	Intermod Levels			Loss in RX Ant dB	Intermod Avail dBm	T/R Isolation dB	Referred to TX dBm
		RX dB/Rx	RX dBm	RX Ant dBm				
7805	3rd	81	-46	-36	36	0	54	+18
4895	3rd	50	-77	-66	43	-23	62	-4
8775	5th	34	-93	-84	33	-51	41	-43
3925	5th	19	-108	-96	47	-49	83	-13
9745	7th	16	-111	-103	31	-71	44	-59
2955	7th	-2	-129	-116	51	-65	100	-16

NOTE 1 Probe antenna approximately 15 feet from T2 antenna and 45 feet from T1 antenna.
2 Intermod at TX computer from power at RX antenna plus T/R isolation.

table 9. This could be an indication that transmitter intermodulation was dominant. However, another method of computation was used to determine expected levels at the transmitter. The levels shown in column 7 of table 14 were referred back to the transmitter by adding the measured attenuation (column 8) and results are shown in column 9. A wide discrepancy exists between the two values shown for each intermodulation order. On the other hand, the column 7 values are nearly balanced as would be expected from intermodulation topside or possibly in the AN/URA-38. A trap was placed in the transmitter line and this greatly reduced the 3rd order level. However, 5th and 7th order levels were not reduced. The most logical conclusion is that the 3rd order levels were primarily from transmitters but that 5th and 7th order levels were from topside sources or the AN/URA-38. This would indicate that transmitter levels for 5th and 7th order were significantly below those shown in column 7 and that computed values shown in table 9 are the upper bounds.

8.0 SUMMARY

8.1 Configurations

Detailed computations were made to determine EMC performance of the AN/URT-23 and R-1051/URR equipments when used in typical shipboard situations. These situations included the following:

a. Smaller ships with AN/SRA-56 multicoupler and broadband antenna (2-6 MHz), whip antennas with AN/URA-38 tuners, and separate receiving antenna with AN/SRA-49 multicoupler as an option.

b. Same as a. but with CARTS decoupling device to allow reception for 2-30 MHz on the broadband transmitting antenna. The AN/SRA-49 multicoupler is used with CARTS.

c. Large ships with 3 broadband transmitting antennas, with AN/SRA-56/57/58 multicouplers, and separate receiving antenna with AN/SRA-49.

d. Same as c. but with AN/SRA-34 multicouplers for transmitting. In all of the above cases the AN/URT-23 and R-1051/URR were assumed for both Link 11 and general purpose circuits. The Link 11 receiver was assumed to operate from the transmitter T/R switch using a 20 dB attenuator or AN/SRA-49 preselector. However, improvement when using a separate receiving antenna for Link 11 was also assessed.

8.2 Computation Methods

Computations were made using techniques developed by reference 1. Threat signal levels, resulting interference levels, and threshold reference levels were determined at key points in the system. Most results are presented in tabular form in foregoing sections. The primary threshold is that of quasi-minimum noise levels expected aboard ship. Interference is compared to this threshold reference and margin (or deficiency) is identified for each computation frequency and situation.

A large number of computations are based on earlier measurements on shipboard equipments. These measurements were made to determine EMC characteristics of specific equipments at various times. This report relates these data to derive expected system characteristics. Extrapolation methods were used in cases where pertinent data were not available.

One of the most important EMC constraints is that of frequency spacing between channels. The parameter of percent frequency spacing is used throughout this document to provide an evaluation tool. Link 11 operation has normally specified a 15 percent separation but it is

understood that 10 percent is used at times. Allowable separation to minimize or preclude equipment related interference was derived from the tables.

8.3 Computed Results for Smaller Ships

8.3.1 Broadband Transmitter Noise

It was found that transmitter noise limits separation to about 9 percent in the 2-6 MHz band when receiving on the transmitting antenna via the T/R switch. If a separate receiving antenna is used the separation can be decreased to 7 percent. For 6-30 MHz, using whip antennas, the required separation is about 15 percent when receiving via the T/R switch. Only a small gain (5-10 dB) is obtained from using a separate receiving antenna. These results are for use of the AN/URA-38 antenna tuner for 6-30 MHz. If the new selectable antenna tuner (SACS) being developed by NRL is used, operation at 7 percent should be possible in the 6-30 MHz band.

8.3.2 Receiver Overload

No problems from receiver overload are expected even at 5 percent separation for any of the configurations used. This includes overload effects of desensitization, cross modulation, and reduced gain.

8.3.3 Intermodulation

Transmitter generated intermodulation at 2-6 MHz is not expected to be a significant problem even at 5 percent separation. The 3rd order intermodulation can be well above minimum expected topside levels or levels from the multicoupler. These frequencies must be avoided anyway because the levels from topside or multicoupler are too high. The 5th and 7th order levels are at or near minimum topside or multicoupler levels even at 5 percent. Multicoupler contribution is expected to exceed transmitter levels but is not significantly above minimum topside levels for 5th and higher orders.

The 6-30 MHz case using AN/URA-38 tuners shows transmitter intermodulation to be in excess of maximum topside levels even for 5th and 7th orders. Since the tuner offers very little selectivity, increasing the frequency separation does not guarantee significant improvement. For that reason, allowable separation cannot be specified with any accuracy. The lack of predictability and the fact that levels are expected to be far in excess of minimum topside levels, leads to a high probability of serious interference at times.

Use of the NRL SACS selective tuner offers major improvement for 6-30 MHz. No transmitter intermodulation problems are expected down to 5 percent separation. Tests must be conducted during the development phase to be sure that intermodulation in the tuner itself is within acceptable levels.

Topside intermodulation can impose significant to serious constraints on system performance. The expected levels referred to in this document range from the upper levels representative of ships in fair condition to lower levels representative of ships in excellent condition. Very few ships qualify for the latter category. This report is not intended to treat the topside source in any detail. Representative levels are used to more effectively evaluate the importance of equipment deficiencies by comparison.

8.4 Large Ships

8.4.1 Broadband Transmitter Noise

Results for 2-6 MHz as discussed in subsection 8.3.1 apply here. Operation at 9 percent separation when using the T/R switch or 7 percent when using a separate receiving antenna is acceptable. If the AN/SRA-34 multicoupler is used instead of the AN/SRA-56, these separations are reduced to 6.5 and 5 percent for T/R switch and separate antenna, respectively.

Since broadband antennas and transmitting multicouplers are used for large ships in the 6-30 MHz band, results are quite different from those for smaller ships using the AN/URA-38 and whip antennas. When using the AN/SRA-57/58 multicouplers and T/R switch option, allowable separations vary from 9 to 15 percent between 6 and 30 MHz. Use of a separate receiving antenna reduces the separations to about 7 percent over the same band. In many cases, the AN/SRA-34 multicoupler will be installed. Its use will reduce separations to 6.5 to 10 percent for T/R switch option or 5 percent for separate receiving antenna over the 6-30 MHz band. More details for the configuration options are shown in table 11, including use of the AN/SRC-23 transmitter in place of the AN/URT-23.

8.4.2 Receiver Overload

No problems of receiver overload are expected for any of the configurations. Operation down to 5 percent or less is acceptable.

8.4.3 Intermodulation

Results are the same as discussed for 2-6 MHz in subsection 8.3.3. No significant problem from transmitter generated intermodulation is expected, even at 5 percent frequency separation. This applies for 6-30 MHz also since broadband antennas and multicouplers are used.

8.5 Validation Measurements

Measurements were made at NOSC (ref 5) concurrently with preparation of this document; they are intended to demonstrate system effectiveness for small ships using the AN/URT-23 and R-1051/URR equipments. Some

of these results are contained in section 7. Results confirmed the applicability of computations contained herein. Absolute values are in reasonable agreement in most instances.

The primary departure resulted from broadband noise measurements for the 2-6 MHz case. Transmitters modified for submarine application and with 400 Hz power were used. Noise levels were considerably higher than predicted for the system. However, measurements made directly at the transmitters showed levels to be high at that point and the system model accurate. Subsequent noise measurements at 6-30 MHz with whip antennas showed good agreement with the computational model. The transmitters were not the same ones used for 2-6 MHz tests and 60 Hz power was used. Further testing is needed to resolve the reason for higher noise when using the modified transmitters and 400 Hz power.

9.0 CONCLUSIONS

Based on computations and validation measurements the following conclusions apply:

a. The computational model provides a good method of predicting EMC performance.

b. The AN/URT-23 transmitter and R-1051/URR receiver are acceptable for smaller ship Link 11 application and for large ship replacements when modified for Link 11 capability.

c. The most important constraint results from broadband transmitter noise. This constrains frequency separation between transmitter and receiver to values ranging from 15 percent at 6-30 MHz using whip antennas and AN/URA-38 tuners down to 5 percent for some configurations on large ships.

d. Use of a SACS selectable tuner in place of the AN/URA-38 results in allowable spacing of about 7 percent.

e. Operation at 2-6 MHz is constrained to about 9 percent separation when receiving on the transmitting antenna and about 7 percent when using a separate receiving antenna.

f. Transmitter intermodulation is not a significant threat when using multicouplers.

g. Multicoupler intermodulation is not a significant constraint unless topside intermodulation is near minimum expected levels.

h. Topside intermodulation can be a major constraint for ships with a large number of hf circuits and high topside levels.

i. 3rd order intermodulation frequencies should be avoided in all cases.

j. Higher order intermodulation frequencies may also have to be avoided, depending on general topside levels.

k. Transmitter intermodulation is a serious threat for 6-30 MHz when using AN/URA-38 tuners but is no threat if the NRL SACS tuner is used.

l. Further tests are needed on AN/URT-23 transmitters to determine the cause of higher broadband noise when using 400 Hz power.

m. Use of a device to de-Q the rf line between transmitter and SRA-56 multicoupler can reduce frequency separation to 6.5 percent with a common antenna or 5 percent with a separate receiving antenna. The AN/SRA-34 has this capability.

n. Use of such a device with AN/SRA-57/58 could reduce separation requirements for large ships using these equipments to 10 percent with a common antenna. The separation could be reduced to 5 percent with a separate receiving antenna.

o. The de-Q device would be required in each transmitter line if used.

10.0 RECOMMENDATIONS

a. Consider the AN/URT-23 transmitter and the R-1051/URR receiver adequate in regard to EMC performance. This applies to both smaller ship and large ship Link 11 use.

b. Continue development of the NRL SACS tuner to replace the AN/URA-38.

c. Use frequency spacings of 15 percent or greater when using whip antennas and the AN/URA-38. Consider use of a separate receiving antenna for a small improvement.

d. Conduct further tests on broadband transmitter noise to assure that levels used in the analytical model are representative of equipments modified for Link 11 use.

e. Consider the use of a device to de-Q transmission line effects when frequency separation cannot be met with AN/SRA-56/57/58 multicouplers. See table 11 for capabilities without the device. Complexity of operation suggests that this device not be used unless frequency spacing deficiency is severe.

11.0 REFERENCES

1. Naval Electronics Laboratory Center Technical Report 1786, "TRED HF Communication System Analysis", by WM Chase and CW Tirrell, 24 September 1971

2. CCIR Report No 322, "World Distribution and Characteristics of Atmospheric Radio Noise", Geneva, International Telecommunications Union, 1964

3. Naval Electronics Laboratory Center Technical Document 437, "CV-2113(X6-1)/SRC Coupler Isolator: Technical Evaluation" by IC Olson and JL Lievens, 31 July 1975

4. Private correspondence from FE Edmonds, DECO Electronics, Inc

5. Naval Ocean Systems Center Technical Document 161, "Small Ship RF Distribution Evaluation for AN/USC-34", by RL Dickson (in preparation)